Method for manufacturing a workpiece and torque transducer module

The present invention resulted from needs encountered in context with endpoint detection when polishing substrates in semiconductor processing. Thereby removing of material has often to be disabled as soon as a material interface separating one material from another is reached.

Nevertheless, the present invention is not restricted to endpoint detection in context with polishing during semiconductor processing, but may be applied to all material removal techniques along a substantially flat plane, where the machining friction varies in dependency of machining depth. Thus, the present invention may be applied

- for endpoint detection of mechanical surface machining. Thereby the resistance which is presented by the workpiece to the machining tool varies unsteadily at such endpoint when a material interface is reached;
- for continuous monitoring of mechanical surface machining whenever the resistance which is presented by the workpiece to the machining tool varies as a function of depth of machining material removal.

As machining polishing and grinding are primarily considered, thereby especially Chemical Mechanical Polishing (CMP).

The invention may thus also be applied to polishing or grinding processing of optical workpieces during manufacturing, thereby and more generically to such

machining of workpieces where thin coatings have selectively to be removed. It may also be applied to grinding in the pharmaceutical industry to control the particle sizes or size distribution as realized by grinding.

The invention may further be applied to non-surface machining, where the mechanical load on a rotating drive varies in time and is significant for a characteristic to be monitored. This is the case e.g. in monitoring varying viscosity of a material. Thus, the invention may also be applied e.g. for monitoring polymerization endpoint or progress in polymer synthesis.

In spite of the fact that the present invention may be applied to a large scale of techniques, we will base the description primarily on considerations in polishing - thereby in CMP technique.

A significant part of yield loss in Ultra-Large-Scale Integration (ULSI) and Very-Large-Scale-Integration (VLSI) microelectronics fabrication can be traced to problems associated with process control. Aggressive shrink of device dimension or increase of package density, or densely packaged workpieces becoming larger as in TFT, LCD and similar manufacturing art, places an increasing demand on process control.

In situ real-time and closed loop process control is recognized as a most effective solution for producing in time, production with high yield and of high quality products. It plays a critical role in achieving market competitiveness.

In the field of semiconductor processing CMP was first introduced as a process to remove and planarize a top layer of material in context with lithography patterning. It also provides a reliable way to form interconnects e.g. in copper and to form Shallow Trench Isolation (STI).

Fig. 1 shows schematically and simplified a typical polishing apparatus as applied for CMP. A turntable 1 is rotatably driven by a motor drive and with a predetermined drive characteristics, as with a controlled rotational speed Ω, around an axis A_1. It carries on its surface a polishing pad 3. A transmission shaft 5 with an axis A_5 parallel to axis A_1 is, in the embodiment of fig. 1, arranged eccentrically with respect to the axis A_1. Transmission shaft 5 is mounted to a substrate carrier 7 carrying a substrate 9 to be polished. The transmission shaft 5 and thus substrate 9 is rotated about axis A_5 with a predetermined controlled drive from a drive motor (not shown), e.g. at a controlled rotational speed ω. Between polishing tab 3 and waver 9 there is applied a predetermined controlled force F. For CMP and as schematically shown in fig. 1 and well known in this art a slurry 11 is dispatched to the surface of the polishing pad 3. For some applications axis A_5 is additionally moved toward and from axis A_1 in a controlled manner.

In the figs. 2A to 2C there is shown a typical application for CMP realized e.g. by an arrangement as shown in fig. 1. The surface S_{10} of a workpiece substrate 10 has been patterned e.g. by applying a photo resist, pattern-development of the resist and dry etching areas free of

photo resist down e.g. to a dry-etch stop ES. The structured surface S_{10} is then coated e.g. by a vacuum coating process with a material m_1. Thereafter a second material m_2 is deposited filling the coated structure and covering the overall surface as shown in fig. 2A.

According to fig. 2B and by means of polishing, especially of CMP as with the apparatus of fig. 1, material m_2 is removed up to reaching a material interface $I_{1,2}$ at which material m_1 transits along distinct areas $AE_{1,2}$ into material m_2. Reaching this interface $I_{1,2}$ may be detected. If the removing process is disabled then the remaining structure is that shown in fig. 2B. If additionally the areas AE_{m1} of material m_1 have to be removed, the polishing process is continued up to reaching the material interface I_{1S} between material m_1 and substrate material. Then the removing process is disabled leading to the remaining structure as shown in fig. 2C.

Very often it is crucial to stop the CMP process or more generically to react by varying parameters of such process at a selected material along a stack of at least one film on the substrate. Over-polishing, i.e. excessive removal of material, leads to device failure and loss of processing yield. Under-polishing, i.e. insufficient removal of material, requires that the polishing process be repeated which is tedious and costly due to significant reduction of production yield. Thus, it is of high importance to monitor polishing depth, thereby at least monitoring when polishing reaches a predetermined material interface.

Several approaches are known to resolve this problem. A first approach resides on simple timing. Thereby the process endpoint, i.e. reaching a predetermined material interface, is determined just by trial and error. Often over- or under-polishing occurs due to process parameter drift, changing properties of the workpiece to be polished etc.

A second approach resides on measuring the thickness of the unpolished workpiece, to determine polishing removal rate and to set processing time according to the removal rate and the desired removal depth. Due to the fact that frequent adjustment and readjustment of the polishing time is necessary and removal rate fluctuation may hardly be monitored during processing, this approach is far from being satisfactory.

A further approach is to monitor audio-sound which may change in a distinct manner at material interfaces. This approach has not gained industrial applicability.

In a still further approach polishing pad temperature is sensed which depends on the heat produced during polishing. This approach has only found industrial application for some specific tasks.

A still further approach is based on induction-sensing systems, which only work when dealing with electrically conductive surfaces.

From the US 5 036 015, 5 069 002 and 5 308 438 and further from the US-A-5 639 388 an approach is known which is based on monitoring the torque with which e.g. shaft 5 of the embodiment of fig. 1 is loaded. Whenever a rotational

movement contributes to the relative movement of workpiece to be polished and polishing surface the rotating transmission shaft for such rotation is loaded with a torque which is dependent on the friction between the instantaneous surface of the workpiece being polished and the polishing surface. As this friction varies with the material or materials and with the surface ratio of areas of such materials, of the workpiece surface being polished, the torque which is loading such transmission shaft is significant for the instantaneously prevailing material and/or the ratio of areas of different materials which simultaneously are exposed to polishing.

According to the prior art documents mentioned, torque is monitored by monitoring the current of an electric motor loaded by such torque. Monitoring such motor current is of limited accuracy, especially when materials changing of low friction as e.g. Tungsten or Titanium Nitride are to be polished, more generically only small frictional changes during the polishing process. Additionally, accuracy of this approach is significantly affected by the fact that small changes or large signals have to be monitored, which leads to significant Signal to Noise problems.

Nevertheless, the present invention does reside on the generic approach of monitoring torque loading of such transmission shaft, the rotation of which at least contributing to the relative polishing movement between workpiece to be polished and a polishing surface.

Under this aspect there is known from the US 6 213 846 to monitor the angle of torsion along a predetermined axial

extent of such shaft due by the torque loading. Without teaching how to realize it is proposed to directly mount on or in the shaft a sensor detecting such deformation. More explicitly this document teaches to apply coaxial rings of reflective portions spaced in axial direction at the outer surface of the shaft and to measure the torque-dependent difference of angle torsion at the respective axially spaced loci by monitoring phase difference of laser beam reflection at the portions of the rings.

This approach suffers nevertheless from a severe drawback. For each transmission shaft a tedious calibration is required and very accurate mount of the reflector rings.

It is an object of the present invention to remedy such drawback and to propose an improved method for manufacturing a plate-like workpiece making use of surface polishing. This object is reached according to the present invention by the method for manufacturing a workpiece which comprises the steps of

- providing a substrate which has a substantially flat surface
- removing material from said surface by moving the surface of the substrate relative to, on and along a polishing surface, wherein
- the relative moving includes a rotation about an axis by a selected transmission shaft which is motor-driven in a predetermined manner;
- there is provided along the transmission shaft a transducer shaft section which has a predetermined

torque to specific torsion angle characteristic, which characteristic of the section being independent of torque to torsion angle specific characteristic of the transmission shaft;

- monitoring a torsion angle at the section as a torque indicative signal;
- controlling removing in dependency of the torque indicative signal and
- manufacturing the workpiece from the substrate having material removed by said removing.

Definition

We understand by the term "specific angle of torsion" the angle of torsion per unit of axial extent of the shaft or shaft section.

Thus, the present invention departs from the recognition that the torque to torsion angle characteristic as exploited in the US 6 213 846 varies with varying cross-section of the transmission shaft as well as with the material thereof, further with operating time of such shaft and respective material fatigue. This makes in fact calibration necessary for every specific transmission shaft before processing.

According to the present invention this problem is resolved generically by applying along the transmission shaft a preferably exchangeable shaft section, whereat the addressed characteristic is independent of the characteristic of the transmission shaft and thus of its cross-sectional area, of its material and of its fatigue

status. Thereby, it becomes possible to apply one and the same transducer shaft section to different shafts, e.g. of different material, different cross-sections and/or fatigue status without any need of recalibrating for accurate torque monitoring by torsion angle detection. The addressed transducer shaft section is tailored on one hand for optimum compromise of angle detection accuracy and mechanical stability to torque loading and to axial force loading.

Although it is possible not to apply to the transmission shaft the workpiece to be polished but the polishing pad, in a preferred embodiment the substrate or workpiece to be polished is carried and rotated by the transducer shaft.

In spite of the fact that, generically, the manufacturing method according to the present invention may be applied for monitoring polishing or, more generically, a material removal progress, as long as such progress varies the torque loading the transmission shaft, in a most preferred embodiment the method according to the present invention is applied where the substrate has at least one material interface between two different materials and substantially parallel to the surface of the substrate, whereby by monitoring the addressed deformation, i.e. angle of torsion, one monitors when material removing reaches such interface. Thus, a more generalized "endpoint" detection is realized. Reaching the interface is detected as endpoint of removing the first material and as an indication as to where the removal process stands. With this information removing is controlled dependent on the application of the

polishing process. Removing may e.g. go on, e.g. transiting from a situation according to fig. 2B to that of fig. 2C after having detected that $I_{1,2}$ has been reached. Possibly the removal process parameters are varied after $I_{1,2}$ has been reached, e.g. relative movement, slurry composition and flow-rate in CMC processing etc. Nevertheless, in a preferred embodiment when reaching a material interface is detected the removal process is disabled.

In a further most preferred embodiment the deformation - torsion angle - is monitored by monitoring strain along the transducer section. Thereby, in a most preferred embodiment strain is monitored by means of the strain sensor arrangement which is mounted to the transducer section and which generates an electric output signal. With an eye on the optical phase-shift measurements according to the US 6 213 846, providing according to the present invention a dedicated transducer shaft section as outlined above, allows providing a sophisticated electronic sensor arrangement generating directly an electric output signal to such section, because one and the same transducer section is most flexibly applicable to different transmission shafts for different machining requirements.

Thus, a further most preferred embodiment of the method according to the present invention is economically feasible, namely transmitting a signal which is dependent on the output signal of the sensor arrangement from the rotating transducer section to a system which is stationary with respect to the transducer section and thereby performing analogue to digital signal conversion of a

signal dependent on the sensor output signal before performing the addressed transmission. Thereby, possibly after preamplification, filtering etc. the analogue output signal of the sensor arrangement is digitized before the critical signal transmission from moving shaft to stationary system is performed. Any signal distortion due to such transmission may easily be restored at the stationary system side due to the fact that the transmitted signal is digitalized.

In a still further preferred embodiment at least a part of the transmission shaft or possibly the entire transmission shaft is provided with a hollow inner space. The section is also provided with a hollow inner space. Both hollow spaces are brought in communication. A signal which is dependent on the output signal of the sensor arrangement is led toward the stationary system via the hollow spaces e.g. by having electrical or optical leads from the sensor arrangement running along these hollow spaces.

The same hollow shaft technique is preferably used for electric power supply to the sensor arrangement, whereby in a less preferred embodiment it is possible to electrically supply such sensor arrangement by a battery or accumulator arrangement integrated into the transducer shaft section or even in a hollow space within the neighboring transmission shaft.

In spite of the fact that it is absolutely possible to transmit a signal which is dependent on the output signal of the sensor arrangement wirelessly to the system stationary with respect to the transducer shaft section, it

has turned out that in a most preferred embodiment such signal transmission is performed via a rotating slide contact arrangement. This is especially true if such signal to be transmitted has already been digitalized. Thereby, such slide contact arrangement is further preferably realized with at least two independent sliding contact arrangements forming redundant transmission paths for the measuring signal to be transmitted from rotary to stationary system.

In view of the fact that the addressed and inventively applied transducer shaft section has a significantly shorter axial extent than the transmission shaft and that the transmission shaft and the transducer shaft section are loaded by the same axial force F as of fig. 1 the transducer sections is conceived for high torque to torsion angle resolution. Bending of this section due to axial force may be neglected. In a most preferred embodiment the transducer section has an outer diameter which is smaller than the outer diameter of the transmission shaft, thereby improving the addressed resolution.

Further, in a most preferred embodiment, the workpiece being manufactured by the method according to the present invention is a semiconductor workpiece, thereby preferably a Low-Scale or Ultra-Low-Scale Integrated microelectronic workpiece. Further preferred, the addressed material removal is performed by CMP, thereby applying a slurry to the polishing surface.

A torque transducer module especially suited for realizing the method of manufacturing according to the present

invention comprises a body which extends along a central axis and which has two end portions. Each of the end portions is a part of an axial mount for a respective part to be axially mounted thereto. The module further comprises a strain gage sensor arrangement with at least one electric output. The module allows flexible mount to one end face of the transmission shaft as was described, the other end portion of the module being mounted to a substrate carrier or possibly a polishing table. Alternatively, the transducer module according to the present invention is mounted on both sides to respective parts of the transmission shaft.

Due to the fact that a strain gage sensor arrangement with an electric output is integrated in the module a most compact, self-contained concept for torque monitoring is provided, which may flexibly be mounted to rotating shafts for a polishing process being loaded by a torque which varies in dependency of polishing conditions as was already explained.

Preferred embodiments of the torque transducer module according to the present invention are further claimed in the claims 17 to 23.

A mechanical surface machining, especially polishing or grinding apparatus according to the present invention comprises a rotatable transmission shaft which is coupled to a drive. It further comprises a torque transducer module - preferable as has been addressed above - which module has a body and two end portions. At least one of the end portions of the transducer module is mounted to a

respective end portion of the transmission shaft. The module has further a strain gage sensor arrangement with at least one electric output.

At the apparatus according to the present invention the transmission shaft and at least a part of the body of the torque transducer module are hollow. Electrical leads are provided in and along the hollow shaft and the hollow body and are operationally connected to the sensor arrangement. Further preferred embodiments of the polishing apparatus according to the present invention are specified in dependent claims 25 to 27.

The present invention further provides for a method for monitoring the load presented by a material on a rotating shaft which is in intimate contact with the material, whereby there is provided along the shaft a shaft section which has a predetermined torque/deformation characteristic. The torque/deformation characteristic of the section is independent of torque/deformation characteristic of the shaft. Deformation of the shaft section is monitored as a load indicative signal.

The present invention under the aspect of method for manufacturing, torque transducer module and polishing apparatus is additionally exemplified in the following description with the help of further figures.

The further figures show by way of examples:

Fig. 3 simplified and schematically, the principal of the present invention, exemplified at a torque transmission shaft arrangement for polishing;

Fig. 4 by means of a simplified signal flow/functional block diagram incorporating a part of the shaft arrangement of the embodiment according to fig. 3, signal sensing and exploitation according to the present invention;

Fig. 5 still in a simplified and schematic representation, a cross-sectional view of a transducer module according to the present invention, mounted to an apparatus according to the present invention, thereby providing for manufacturing of workpieces according to the invention or to load monitoring according to the invention;

Fig. 6 in a simplified schematic representation in analogy to that of fig. 5, a further preferred embodiment of a transducer module according to the present invention to be mounted to an apparatus according to the present invention, thereby providing for manufacturing of workpieces according to the present invention or to load monitoring according to the invention, and

Fig. 7 over the time axis torque and torque derivative as measured with a transducer module according to the present invention as indicative for reaching subsequently two material interfaces.

In fig. 3 there is shown, most simplified and schematically, an apparatus according to the present invention incorporating a torque transducer module according to the present invention and operating the

manufacturing method according to the present invention. A substrate 30 has a substantially flat surface 32 to be machined. The substrate is moved relative to a polishing surface 34, as upon a table 1 according to fig. 1, by rotation ω. A rotational drive is applied to the substrate 30 via a shaft arrangement 36. A substrate carrier table 38 is mounted to one end of shaft arrangement 36 and a drive motor M is operationally coupled to the shaft arrangement 36. There is applied a predetermined axial force F via the shaft arrangement 36 onto the substrate 30 for efficient machining i.e. polishing of the surface 32 along polishing surface 34. Thereby, at least a part of force F may be generated by the weight of shaft arrangement 36 and substrate carrier 38.

The shaft arrangement 36 comprises a transmission shaft 39. In the embodiment of fig. 3 the shaft 39 is of two parts 39a, 39b which have been made e.g. by cutting a one-piece shaft 39 in two parts. Coaxially with transmission shaft 39 a transducer shaft section 40 is provided, which is preferably removably and exchangeably mounted to transmission shaft 39 as schematically shown at the end portions of the transducer shaft section 40, at 41.

Due to rotation of the surface 32 on and along polishing surface 34 the shaft arrangement 36 experiences a loading torque T. This torque T causes, as perfectly known to the skilled artisan, the shaft arrangement 36 to be twisted by a torsion angle. Per unit of axial extent, the shaft arrangement is twisted by the specific torsion angle φ, which latter is dependent on material, shape and dimension

of the shaft arrangement at an axial locus considered. If we consider a slice 37 of thickness "1" of the shaft arrangement 36 at locus x_{37}, it is the material of this slice 37 and the cross-section shape and dimension of that slice which govern the angle φ_{39} at a specific value of torque T.

Assuming that the transmission shaft 39 has a constant cross-section Q along the axis A_{36} and material does not change along that axis A_{36} the transmission shaft 39 has a characteristic of $\varphi_{39}(T)$, e.g. as qualitatively exemplified in fig. 3. The transducer section 40 of shaft arrangement 36 is conceived to have a $\varphi_{40}(T)$ characteristic which is independent of the $\varphi39(T)$ characteristic of the transmission shaft 39.

Whereas the transmission shaft 39 is conceived for standing the loading torque T, the axial force F and to provide by its axial extent L transmission-coupling from drive M to table 38, the transducer shaft section 40 of significantly smaller axial extent $l << L$ has in fact one task, namely to provide for a steep $d\varphi_{40}/dT$-slope. It just must stand force F, but its short extent l results in negligible problems of bending.

The $\varphi_{40}(T)$ characteristics at the section 40 is selectively tailored by respective selection of material and/or cross-sectional shape. The characteristic $\varphi_{40}(T)$ will not change when the transducer section, now as a flexibly applicable module, is applied to different transmission shafts 39 with different $\varphi_{39}(T)$ characteristics.

As shown in fig. 4, still schematically, there is mounted a sensor arrangement 42 preferably with a commercially available strain gage on the transducer section 40. It generates an output signal A_{42} which is dependent on specific torsion angle φ_{40} at section 40. The output signal A_{42} is operationally connected to a control unit 44 which controls generically the polishing process in dependency of the output signal A_{42}.

As by signal A_{42} real-time monitoring of φ_{40} as a torque indicative entity is realized, which torque is indicative of the instantaneously prevailing characteristic of the polishing process, the unit 44 may be conceived with a difference forming unit 45. One input thereof is operationally connected to the output of sensor arrangement 42, the second to a setting unit 46 for a desired value of angle φ_{40} and thus of torque. The output of unit 45 is operationally connected to at least one control input of a unit 48, which adjusts the polishing process. Unit 48 may comprise at least one of motor drive M, force F generating unit 48a, slurry composition or flow control unit 48b. Thus a negative feedback control loop for the polishing process is realized whereat the signal A_{42} is the measured value and the parameter set at unit 46 is the desired torque-indicative value $\varphi_{40W}(T_W)$.

In an open loop control manner, e.g. when A_{42} shall just be indicative of reaching a material interface (endpoint detection) the control unit 45 disables the polishing process, when A_{42} experiences e.g. a predetermined, preset time derivative as shown in dashed lines in Fig. 4.

Although the surface of the substrate to be polished could possibly be provided instead of polishing surface 34 of fig. 3, the polishing surface being provided at table 38, in a most preferred embodiment and as exemplified in fig. 3 the substrate 30 to be treated is mounted to the rotating shaft arrangement 36.

In fig. 5 there is shown in a simplified cross-sectional representation on one hand of a preferred form of realization of the transducer shaft section as was previously described, but, on the other hand, realized by a transducer module according to the present invention and further applied to the transmission shaft of a polishing apparatus according to the invention. According to fig. 5 the transducer shaft section is formed by a transducer module 50. The transducer module 50 comprises a hollow cylindrical base body 52. At both ends the base body 52 has respective end portions 54a and 54b which respectively form a part of a mount for coaxially mounting portions of transmission shaft 39 on both sides according to fig. 3, or as shown in fig. 5 a transmission shaft 39 on one side and a workpiece carrier table 7 according to fig. 1 to the other side of module 50. The respective coaxial mounts are established by screwing, possibly quick connectors, as e.g. bayonets, as long as such mounts are capable of transmitting the loading torque T.

As shown in fig. 5 the outer diameter Φ_{50} of the main part of cylindrical base body 50 is selected smaller than the outer diameter Φ_{39} of the transmission shaft 39, combined with a selected material of base body 52, providing for the

desired $\varphi_{50}(T)$ characteristic independent and mostly different from the characteristic $\varphi_{39}(T)$ of the transmission shaft 39.

There is provided a recess 56 in the base body 52, preferably at the outside surface of body 52 and in a most preferred form, as shown in fig. 5, defined between the end portions 54 which latter define for projecting rim portions 58.

Within recess 56 the sensor arrangement 60 is mounted, preferably comprising strain gages affixed to the outer cylindrical surface of base body 52. The electric output signal as schematically shown at an electric output A_{60} of the strain gage sensor arrangement 60 is operationally connected, possibly via a filtering and/or preamplifier stage (not shown), to the analogue input of an analogue to digital converter unit 62. Thus, the sensing and signal processing electronics are mounted to the base body 52, as shown in fig. 5 preferably in an appropriately provided recess along the outer surface of base body 52. There is further provided a cover 64 which is, for the embodiment of fig. 5, cylindrical and may be slided in axial direction over the recess 56. O-ring seals are preferably provided so as to seal the recess 56 with the sensing electronics therein from industrial environment.

The cover 64 is preferably made of a metal shielding electromagnetic disturbances from the industrial surrounding.

The output A_{62} of the analogue to digital converter unit 62 is preferably fed through the wall of base body 52 into

hollow inner space 70_{52} of body 52. The output signal of the sensing electronics, preferably in digitized form, is led via a conductor lead 72 along hollow space 70_{52}, then along a hollow space 70_{39} of transmission shaft 39 to an end portion 73 of shaft 39.

As schematically shown in fig. 5 shaft arrangement 36 is driven e.g. via a gear arrangement 74 relative to a stationary system 76. Signal transmission from lead 72 in the rotary shaft system to stationary system 76 is preferably performed, as schematically shown in fig. 5, via a sliding ring contact arrangement 78. Thereby, coaxially to axis A_{36} contact rings 80 are provided on the rotary system side and contact rings 82, aligned with rings 80, on the stationary system side. In a preferred embodiment bridging contact between the rings 80 and 82 is established by conductive balls 84. Lead 72 is connected to one, preferably and as shown in fig. 5 to more than one contact ring 80, and the digitized electrical signal is transmitted via one or preferably more than one sliding contact to the stationary system side 76, there to be exploited as has been exemplified schematically in fig. 4.

By the fact that on one hand the analogue output signal of the sensor arrangement or a signal dependent therefrom is first converted to digital form, dealing with that signal is significantly simplified in view of introducing noise and distortions and allows the addressed transmission of this signal by friction contact from the dynamic rotary system to the stationary system. Providing redundancy by at least double-parallel transmission reduces transmission

resistance and additionally improves uninterrupted signal transmission.

The electronic in recess 56 is supplied with electric energy preferably via the arrangement 78 as shown in the figure.

It must be emphasized that instead of the preferred rolling contact arrangement, as realized by the balls 84, a mere sliding system for signal transmission may be provided where contact between the rims 80 and 82 is established in a sliding rather than in a rolling manner.

In fig. 6 there is shown a further embodiment of a transducer shaft section or module according to the present invention. The transducer shaft section 90 comprises a hollow cylindrical support 92. The base body 94 which is at both end portions 94a and 94b rigidly mounted to shaft 39 - as by screw-bolts 95 - defines for a cylindrical recess 96 which is closed towards hollow space 98 by the support 92. The sensor arrangement 60 is mounted to the base body 94 within recess 96, wherein there is further mounted the sensor electronic with the analogue to digital converter unit 62. The support 82 has in fact only the task of closing recess 86 towards the hollow space 88 and may contribute to the support for electronic unit with converter unit 62. It is supported and sealed by and towards base body 94 at sealing and fixating areas 91.

With a transducer module substantially as has been exemplified with the help of fig. 5 the signal at lead 72 was monitored on the stationary system 76. With respect to dimensioning the following was valid (s. fig. 5):

Φ_{50}: 26.54 mm

Φ_{51}, inner diameter: 22.54 mm

Shaft Diameter Φ_{39}: 46.99mm

Both the shaft 39 as well as the base body 52 of the transducer module were made from hardened high-grade steel.

As sensor arrangement, exemplified by reference Nr. 60 in figs. 5 and 6, a metal-film based strain gauge arrangement may be used, a semiconductor based strain gauge or a piezo-electric strain gauge. Nevertheless most preferably a Fiber-Optic Bragg Grating strain gauge arrangement is used. Such strain gauges are commercially available from Fisco Technologies, Sainte-Foy (Quebec) Canada and described for application in Application Note, Fisco Technologies, Doc: APN-FPI-9901 and in J.D. Muhs, "Fiber Optic Sensors: Providing Cost- Effective Solutions to Industry Needs", Oak Ridge National Laboratory, US Department of Energy, November 2002.

The transducer module may further be implemented in the shaft driving the workpiece to be machined e.g. polished or in the shaft driving the machining table e.g. with the polishing pad. In a further embodiment one transducer module is implemented in the shaft driving the workpiece, one transducer module is implemented in the shaft driving the machining table.

The shaft driving the workpiece is rotating or rotatingly oscillating whereas the machining pad may rotate or may be moved linearly possibly in an oscillating manner. Further the sensing arrangement 60 may be mounted to the outer surface of the transducer module as shown in fig. 5, or may be mounted to the inner surface of the transducer module as shown in fig. 6.

Still further the signal transmission arrangement - between rotating system and stationary system as exemplified in fig. 5 - for signal transmission as well as for supply-power transmission, based on a contacting ring arrangement, may be realised as a slip-ring

arrangement or as a roll-ring arrangement. As shown in fig. 5 the contacting rings may be realised in a plane one inside the other thus with different diameters or staggered in axial direction preferably with equal diameters."

Fig. 7 shows a typical measurement result when a workpiece was machined by CMP which workpiece provided for two subsequent material interfaces I_A and I_B. In fig. 7 the time axis is scaled in seconds and the signal axis S is scaled in torque (inch*pounds). Course (a) is directly the torque-dependent signal, whereas course (b) is its time derivative (see fig. 4). It may clearly be seen that the torque (a) is constant up to reaching the first material interface I_A at time t_{IA}. Sharp slopes of torque and its time derivative very accurately indicate reaching the first material interface I_A.

Then the torque remains substantially constant up to second material interface I_B, which is reached at time t_{IB}. Here again sharp slopes in torque and its derivative indicate very accurately reaching the second material interface I_B. Both torque slopes at the respective material interfaces may accurately be exploited as machining endpoints.

As may be seen in fig. 7 torque was set to be zero at first surface machining. The rotational speed of polishing was 60 rpm.

With the method, the module and the apparatus according to the present invention, it becomes possible to most accurately monitor the torque applied to a transmission shaft and especially for most accurate controlling polishing operation, especially CMP. Due to the exchangeability of the addressed transducer module calibration efforts are minimized and interruption of a manufacturing process is minimized. Whenever a transducer module is recognized causing problems, such module may quickly be exchanged.